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Demographic Catastrophes Did Not Shape the Growth of Human Population or the Economic Growth

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Abstract. Rigorous analysis of demographic catastrophes shows that, individually, they were too weak to shape the growth of human population and of the associated economic growth. On average, only 6.5% of all major demographic catastrophes, associated with the death toll larger than or equal to one million, were potentially strong enough to cause perhaps a minor change in the growth trajectory of the world population, but as shown by the population data, they did not produce any noticeable disturbance. The absence of impacts of demographic catastrophes on the growth of population can be explained not only by their low relative intensity but also by the strong and efficient regenerating process recorded for the first time by Malthus. There was, however, one unusual event manifested in the convergence of five, major demographic catastrophes. They have caused a minor and short-lasting change in the growth trajectory of the world population, which, however, was soon counteracted by the process of regeneration. This analysis shows that the dominant force controlling the growth of human population was too strong to be influenced in any substantial way by accidental forces. As explained in an earlier publication, this strong and dominant force driving the growth of population was the force of procreation, which was approximately constant per person, the force expressed as a difference between the ever-present, biologically-controlled, force of sex drive and the ever-present and also biologically-controlled process of aging and dying.
Keywords: Demographic catastrophes, Growth of population, Economic growth, Malthusian stagnation, Hyperbolic growth, Mechanism of hyperbolic growth.
JEL. A10, A12, A20, B41, C12, Y80.

1. Introduction

Demographic catastrophes were supposed to have shaped the growth of human population and indirectly also the economic growth because as indicated by Maddison's data (Maddison, 2001; 2006; 2010) these two processes are strongly correlated. Demographic catastrophes were supposed to have been responsible for creating the alleged, but non-existent, epoch of Malthusian stagnation in the growth of population and in the associated economic growth. This concept, which was accepted for decades in the demographic and economic research, has been recently reinforced by Galor and his associates by the deliberately distorted presentation of data (Ashraf, 2009; Galor, 2005a; 2005b; 2007; 2008a; 2008b; 2008c; 2010; 2011; 2012a; 2012b; 2012c; Galor & Moav, 2002; Snowdon & Galor, 2008). We have discussed this issues in earlier publications and we have shown that *precisely the same data*, which were used in their distorted way by Galor and his associates to support their preconceived but erroneous ideas, *are in fact in the direct contradiction of the concept of Malthusian stagnation* (Nielsen, 2014; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h).

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The erroneous concept of Malthusian stagnation and takeoffs from the alleged but non-existent Malthusian trap in the demographic and economic growth is based on the incorrect interpretations of hyperbolic distributions. They are indeed slow over a long time and fast over a short time but they increase *monotonically* and there is no place on them where they change suddenly from being slow to being fast. In order to explain the mechanism of hyperbolic growth, hyperbolic distributions have to be treated as a whole. They cannot be divided into two or three different regimes of growth as incorrectly imagined by Galor (2005a; 2011) and by many other researchers.

In the discussion presented here we shall extend our earlier discussions of the growth of human population by concentrating our attention on the possible impacts of demographic catastrophes. We have already explained (Nielsen, 2016i) that in harmony with the observation published by Malthus (1798), his positive checks (demographic catastrophes and harsh living conditions) have a dichotomous effect on the growth of population: they are destructive by increasing the death toll but they are also constructive by triggering the process of regeneration. In the discussion presented here we are going to demonstrate that there is also another reason why demographic catastrophes did not shape the growth of human population: they were generally too weak to have any tangible impact. They might have been strong enough to upset the growth of some local populations but with only one exception discussed earlier (Nielsen, 2016j) when there was an unusual convergence of *five* remarkably strong demographic catastrophes, they had no effect on the growth of global population, or even on the growth of regional populations (Nielsen, 2016d).

2. The alleged age of pestilence and famine

In one of his publications, Lagerlöf stated that "Throughout human history, epidemics, wars and famines have shaped the growth path of population" (Lagerlöf, 2003a, p. 435). He studied the growth of population in England, France and Sweden using his model of growth, which incorporated the concept of Malthusian stagnation. Similar calculations were carried out earlier by Artzrouni & Komlos (1985) for the world population. These two studies are most interesting because when closely examined they show that the mechanism of stagnation does not produce expected results (Nielsen, 2016k). It did not produce a stagnant state of growth. Lagerlöf missed the opportunity of seeing it because he did not compare his model calculations with data. Artzrouni & Komlos (1985) produced a distribution for the growth of the world population but did not notice that their model generated exponential growth with no signs of stagnation. Furthermore, their results are contradicted by data (Nielsen, 2016k) because the world growth of population was never exponential (Nielsen, 2016d; 2016j).

Lagerlöf carried out Monte-Carlo calculations, which were supposed to confirm the existence of the epoch of Malthusian stagnation in the growth of population allegedly caused by the effects of demographic catastrophes, such as epidemics, wars and famines. He incorporated explicitly the mechanism of stagnation in his model. Consequently, his model should have been expected to produce the process of stagnation but *it did not*. Before the publication of Lagerlöf's paper, data for the United Kingdom, France and Sweden were already available (Maddison, 2001) but unfortunately Lagerlöf did not compare his model-generated calculations with these most essential data.

These data are shown in Figure 1. Their analysis demonstrates that data for the UK and France follow hyperbolic trajectories. For Sweden, there was a change from a hyperbolic distribution to exponential growth. All these data and their analysis demonstrate that there was *no stagnation* in the growth of population and that contrary to the original assumption of Lagerlöf, "epidemics, wars and famines" *did not shape* "the growth path of population". The past growth may have been slow but it was not stagnant. It was slow because it was hyperbolic. It then became fast because it was hyperbolic. Only in Sweden it was diverted to a faster new trajectory but it was not a transition from stagnation to growth but a transition from growth to growth, from a hyperbolic growth to an exponential growth.

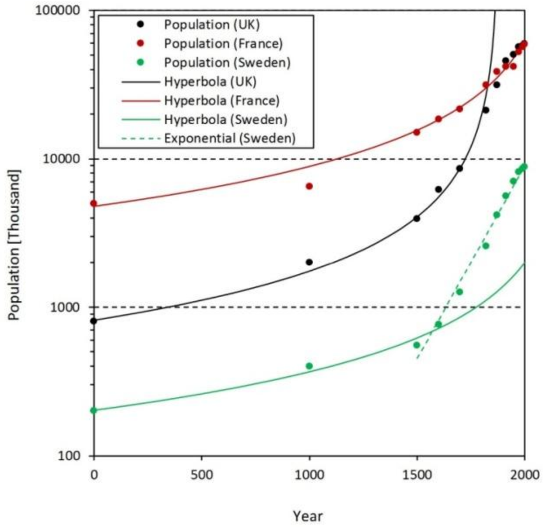

Figure 1. *Population growth in the United Kingdom, France and Sweden. Data (Maddison, 2001) are compared with hyperbolic distributions. Population growth was increasing monotonically. It was slow in the past because it was hyperbolic. For Sweden, there was a change from a slow hyperbolic growth to a faster exponential growth around AD 1600. There was no stagnation. The growth of population was not shaped by demographic catastrophes, as claimed by Lagerlöf (2003a).*

For France, the growth of population was following closely hyperbolic distribution at least until around 2000. For the United Kingdom, the growth was hyperbolic until around 1820, when it started to be diverted to a *slower* trajectory. According to the generally accepted interpretations of the mechanism of the growth of human population, we should expect a significant boosting (takeoff or explosion) around the time of the Industrial Revolution, 1760 and 1840, (Floud & McCloskey, 1994). This takeoff should be clearly indicated in the United Kingdom, the very centre of this revolution, where its impacts should have been most clearly demonstrated. The takeoff did not happen. On the contrary, in the direct contradiction of these usually claimed expectations, the growth of population in the UK started to be diverted to a *slower* trajectory at around 1820, right at the time when it was supposed to have been boosted.

In Sweden, the growth of population was boosted but it was boosted at a wrong time, around AD 1600, i.e. well before the Industrial Revolution. The boosted growth follows an exponential trajectory, as indicated by the straight line in this semi logarithmic display.

Hyperbolic distributions displayed in Figure 1 are described by the following simple equation:

$$S(t) = \frac{1}{a - kt}, \tag{1}$$

where $S(t)$ is the size of the population, t is time, while a and k are the parameters determined by fitting hyperbolic distributions to data.

For the hyperbolic distributions displayed in Figure 1, parameters are: $a = 1.221 \times 10^{-3}$ and $k = 6.511 \times 10^{-7}$ for the UK, $a = 2.085 \times 10^{-4}$ and $k = 9.635 \times 10^{-8}$ for France and $a = 4.935 \times 10^{-3}$ and $k = 2.221 \times 10^{-6}$ for Sweden.

Exponential distribution describing the growth of population in Sweden from AD 1600 is given by the following equation:

$$S(t) = be^{rt}, \tag{2}$$

with parameters $b = 5.798 \times 10^{-2}$ and $r = 5.973 \times 10^{-3}$. From AD 1600, population in Sweden was increasing at an approximately constant rate of 0.6%. Just before the transition to this new trend, the growth rate for the preceding hyperbolic distribution was only 0.16%. The new exponential trajectory was approximately 3.7 times faster than the preceding hyperbolic trajectory at the time of the transition.

Hyperbolic growth is often described as "faster-than-exponential" or "hyper-exponential". Such descriptions should be avoided. They are inaccurate and misleading. The concept of the faster-than-exponential growth was introduced, or at least strongly promoted, by Bartlett (1993). However, he has readily admitted that he was wrong: "Thanks for your thoughtful analysis of my writing about faster and slower than exponential. You are right! My wording is unclear and confusing and wrong. I have used these terms for years and you are the first person to point out this error to me" (Bartlett, 2011). If only the erroneous concepts adopted in the economic and demographic research could be so readily corrected we would see progress in these two fields of study, rather than the existing and long-lasting stagnation.

In the example presented in Figure 1, exponential growth in Sweden after around AD 1600, is faster than the preceding hyperbolic growth and thus, in this case, hyperbolic growth (the so-called "faster-than-exponential" growth) is in fact slower than exponential.

We can only compare *specific* distributions and see which of them are faster or slower. Faster-than-exponential distributions do not exist because we can always design exponential growth, which over a certain time will be faster than some other incorrectly claimed faster-than-exponential growth.

If we have to use the expression "faster-than-exponential" we have to be specific. We have to describe clearly, which specific distributions are being compared and over specifically what range of the independent variable. Thus, for instance, for the distributions shown in Figure 1 for Sweden we could say that over the range of the displayed time, the exponential growth, which commenced in 1600 was faster than the preceding hyperbolic growth. However, we obviously cannot claim that the hyperbolic growth before 1600 was "faster-than-exponential" or "hyper-exponential" because we have already demonstrated that in this particular case this so called "faster-then-exponential" or "hyper-exponential" growth was obviously slower than the exponential growth, which replaced this hyperbolic growth.

Lagerlöf did not invent the concept of Malthusian stagnation, which is supposed to be caused by the lethal effects of demographic catastrophes. He just accepted it without any criticism maybe because going with the flow increases the chance of publishing new results. When in one of his papers, published also in 2003, Lagerlöf was associating the hypothetical epoch of Malthusian stagnation with "epidemic shocks" he was quickly corrected by a referee for missing the effects of wars: "As suggested by a referee, this process could possibly be interpreted in terms of wars, instead of epidemics" (Lagerlöf, 2003b, p. 766).

Both, Lagerlöf and his referee were wrong. The process of Malthusian stagnation cannot be interpreted "in terms of wars, instead of epidemics" because as shown by data presented in Figure 1, Malthusian stagnation did not exist. However, neither Lagerlöf nor his referee cared to consult the relevant data. Data appear to be of lesser importance than the mantra of stagnation.

Unfortunately, this mantra is repeated without any convincing justification in the economic and demographic research, and every effort is made to make sure that it is repeated faithfully and as required. As mentioned earlier, Lagerlöf did not compare his model-calculations with data, but his referee was also misguided because the doctrine of Malthusian stagnation is repeatedly contradicted by data (Nielsen, 2016a; 2016d; 2016j).

According to the established knowledge in demography and in economic research, "The age of pestilence and famines lasted until 1875" (Rogers & Hackenberg, 1987, p. 234) when there was supposed to have been a transition from stagnation to a fast growth, the transition described usually as a takeoff or explosion. It is unclear how this precise date was determined but it might have been suggested by the generally accepted but erroneous notion of the alleged transition from stagnation to growth around the Industrial Revolution, 1760 and1840 (Floud & McCloskey, 1994). Analysis of data shows convincingly that there was no stagnation in the growth of population and in the economic growth, and that there was no transition, which could be described as a takeoff or explosion. What is interpreted as an explosion is just the natural continuation of hyperbolic growth (Nielsen, 2016a; 2016d; 2016j).

The mythical age of pestilence and famines was supposed to have been characterised by what is known as Malthusian oscillations. According to this doctrine "…periodic epidemics of plague, cholera, typhoid and other infectious diseases would in one or two years wipe out the gains made over decades. Over long periods of time there would, consequently, be almost no population growth at all" (van de Kaa, 2010, p. 87). "The pattern of growth [of human population] until about 1650 is cyclic" (Omran, 1971, Table 4, p. 533). Here we have a different date for the termination of the age of pestilence and famine, which is hardly surprising because these dates are based on impressions combined with a good dose of imagination. The age of pestilence and famine, with its assumed strong effects on the growth of population and on the economic growth, did not exist.

The alleged, but non-existent, transition from stagnation to growth was supposed to have been associated with the transitions in the birth and death rates. It is interesting, however, that while Omran shows examples of the claimed transitions in birth and death rates, his examples (for Sweden, England, Japan, Ceylon and Chile) show clearly and convincingly that these transitions had absolutely no impact on the growth of population (Omran, 2005).

Changes in birth and death rates are not necessarily reflected in changes in the growth of population. The growth of population is not determined by the birth and death rates alone but the *average difference*, i.e. by the *average gap*, between these two quantities. Birth and death rates might be changing from high to low but such changes will not be reflected in the growth of population unless the average difference between them is also changing. Furthermore, small changes in the difference between birth and death rates are also not reflected as the associated changes in the growth of population (Nielsen, 2016l).

Birth and death rates might be decreasing but if they are decreasing in such a way that the average difference between them is approximately constant, the growth of population will be approximately exponential. If the difference increases systematically, then the growth of population will be described by a non-exponential trajectory. For instance, if the difference increases, on average, hyperbolically, then the growth of population will be hyperbolic.

To produce stagnation, the average difference between birth and death rates has to be approximately *zero*. To produce a stagnant but slowly increasing population, the average difference between birth and death rates would have to be changing in a very specific and complicated way. It would have to be on average zero over a long time but then it would have to be on average non-zero to generate growth. Then again it would have to revert back to zero to produce stagnation. This process would have to be repeated over a long time for thousands of years. We do not have data to demonstrate that such a process ever existed. We do not have data for birth and death rates extending over thousands of years. The claim that birth and death rates were high and that they were producing stagnation is *unscientific* because we do not have data to prove it. However, we have a large body of data describing the growth of population and we can show that the growth of population was in general hyperbolic, which by inference means that the average difference between birth and death rates was increasing hyperbolically. *There was no stagnation.*

To demonstrate a dramatic change from stagnation to growth in the growth of population we would have to demonstrate that there was a dramatic change in the average difference between birth and death rates from zero to a clearly and systematically larger value, and it does not matter whether birth and death rates were decreasing or increasing. What determines the growth of population is the average difference between birth and death rates.

If we want to claim some kind of transitions in birth and death rates, there is nothing to stop us from doing it. However, we should remember that, in general, such studies will not help us to understand the mechanism of growth of population. They might be interesting and stimulating for another reason but unless we pay close attention to *how* the difference between these two quantities is changing, how large or how systematic are these changes, and how these changes can be explained, we shall not explain the mechanism of growth of human population. We also should remember that only *significant* changes in the difference between birth and death rates are reflected as changes in growth trajectories.

The frequently used example in support of the concept of stagnation followed by explosion is the growth of population in Sweden between around AD 1750 and 2000. It shows changes in the difference between birth and death rates but no-one seems to have noticed that these changes are relatively small. Furthermore, no-one seems to have noticed that these small changes are not reflected in the growth of population, even though data for the birth and death rates and for the growth of population come *from exactly the same source* (Statistics Sweden, 1999). These data are selectively and consistently ignored in order to preserve the perfect intonation of the mantra of Malthusian stagnation.

Small changes in the average values of birth and death rates are repeatedly but incorrectly interpreted as a proof of the existence of the epoch of Malthusian stagnation and of a transition from stagnation to growth while data presented *in the same primary source* show clearly that the growth of population in Sweden was *increasing monotonically without any signs of stagnation* and without any sign of a transition from stagnation to growth. These issues were discussed earlier (Nielsen, 2016l).

Demographic research concentrating on the study of birth and death rates might be important but it is incorrect to think that such a research can be necessarily useful for explaining the mechanism of growth of human population. The two mechanisms are related only via the average difference between birth and death rates. There might be strong fluctuations in birth and death rates but these fluctuations are generally not reflected in the growth of population. They might be reflected only as minor variations in the growth trajectory describing the growth of population.

In conformity with the established knowledge, Komlos claimed that "Malthusian positive checks (mortality crises) maintained a long-run equilibrium between population size and the food supply" (Komlos, 1989, p. 194). Here we have a hinted link to the specific type of demographic catastrophes: famines. He also claimed that "the food-controlled homeostatic equilibrium had prevailed since time immemorial" (Komlos, 2000, p. 320). Komlos appears to have been guided by the generally accepted consensus. However, science never relies on any generally accepted consensus. It is not unusual in science to show that the generally accepted consensus is scientifically unacceptable.

The postulate of Malthusian stagnation in the economic growth and in the growth of human population, as well as all other related postulates, are scientifically unacceptable. because they are systematically contradicted by data (Nielsen, 2014; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; von Foerster, Mora & Amiot, 1960). Growth of population, global or regional, was hyperbolic, (Nielsen, 2016d; 2016j; von Foerster, Mora & Amiot, 1960). Economic growth was also hyperbolic (Nielsen, 2016a).

In the case of the growth of human population we can extend our study to 10,000 BC. It is remarkable, that over the past 12,000 years the growth of population was not only hyperbolic but also exceptionally stable (Nielsen, 2016j) because over this long time there was *only one major* transition around AD 1 from a fast to a slow hyperbolic trajectory. There was also another but only *minor* transition around AD 1300 from a slower to a slightly faster hyperbolic growth. Currently we are experiencing a new transition to a yet unknown trajectory but the growth is still close to the historical hyperbolic trajectory.

We can extend the analysis of the growth of population even further, over the past 2,000,000 years and show that the growth was hyperbolic (Nielsen, 2017). There is nothing in the data to support the claim that "Throughout human history, epidemics, wars and famines have shaped the growth path of population" (Lagerlöf, 2003a, p. 435).

We already know that Malthusian positive checks, which include demographic catastrophes, trigger the process of regeneration (Malthus, 1798; Nielsen, 2016i). This process alone, explains the remarkable stability of the growth of human population. However, in order to understand even better why demographic catastrophes had generally no impact on the growth of population we shall now investigate their relative intensity and other parameters defining their possible impact.

3. Preliminary remarks

Impacts of demographic catastrophes depend on the *death toll,* their *duration* and on the *size* of population. Death toll for a given demographic event might be high but to understand its impact we have to express it as *the relative impact* by comparing the death toll with the size of population, which could be the size of local population directly affected by a demographic crisis or it could be the size of a regional or global population, depending on whether we are interested in the study of local, regional or global impacts.

Impacts of demographic catastrophes depend also on the historical time. In the distant past, when the population was small, local impacts of demographic catastrophes could be large. However, people were living in greater isolation so the global or even regional impacts could have been small. Likewise, at the other end of the historical time scale, when the population increased to a certain large size, relative impacts were small even if the number of people killed by a given demographic catastrophe was large. It can be, therefore, expected that there is only a relatively small window of time, mainly during the AD era until around 1800, when the global population reached its first billion, or maybe until around 1900, that the demographic catastrophes could have had a noticeable impact on the growth of population. However, the study of human population shows that in general they had no damaging impact, with the exception of the already mentioned minor disturbance around AD 1300 (Nielsen, 2016j).

The further we go back in time with our investigation the less we know about the intensity of demographic catastrophes but we have enough information for the AD era to assess their possible impacts.

In order to understand human population dynamics, it is essential to identify the *main* and the most obvious driving force of growth and add to it any other force or forces only if the assumed main force cannot explain growth. The fundamental force of growth of human population is obviously the force of procreation expressed as the difference between the *biologically-controlled* force of sex drive and the *biologically-controlled* process of aging and dying. This force cannot be dismissed and it turns out that this force alone explains why the spontaneous and unconstrained growth of human population is hyperbolic and why for the most part of the past human history it was hyperbolic (Nielsen, 2016m).

In the past 12,000 years, other forces were playing a significant role only during the major demographic transition around AD 1 and during the minor transition around AD 1300. They are also strong and active during the current transition. With the exception of these rare events, the growth was hyperbolic in the past 12,000 years. Furthermore, with the exception of the minor disturbance around AD 1300, there is no evidence that demographic catastrophes were ever shaping the growth of human population (Nielsen, 2016d; 2016j).

It should be also noted that the recorded impacts of demographic catastrophes are likely to be exaggerated. Recorded death rates "are largest when the supporting evidence is skimpiest. When data are better, the death rates are usually lower and the percentage increases less" (Watkins & Menken, 1985, p. 651). For instance, both Durand (1960) and Fitzgerald (1936; 1947) claim that impact of the An Lu-Shan Rebellion (AD 756-763) is probably exaggerated. Likewise, Russel (1968) and Twigg (1984) believe that the number of casualties caused by the Justinian Plague (AD 541-542) is also grossly overestimated.

Another example is the Antonine Plague (AD 166-270), which was first estimated to have killed about 50% of the population of the Roman Empire (Seeck, 1921). However, this estimate was later downgraded to 1-2%, or to the total number of casualties of 500,000-1,000,000 (Gilliam, 1961) and then upgraded to 7-10% or to a maximum of 5 million (Littman & Littman, 1973), the last estimate being still significantly smaller than the original estimate. It appears that the further back in time we go the larger is the possibility of exaggerated claims of the number of casualties.

We shall describe demographic catastrophes in the way they are reported in the literature. However, labelling them with just a single cause might not be accurate. For instance, a war considered as the main cause of a crisis might include famine but famine might be linked with pestilence. For example, during the Madras famine in the 1870s, about 40% of casualties were caused by smallpox and cholera (Lardinois, 1985). The Justinian Plague was also accompanied by smallpox, diphtheria, cholera and influenza (Shrewsbury, 1970) and was "perhaps aided by wars, famines, floods and earthquakes" Scott & Duncan (2001, p. 5). Likewise, "a number of epidemics in France were preceded by famine, sometimes in conjunction with bad weather conditions" (Scott & Duncan, 2001, p. 105) whereas "frequent and virulent outbreaks in France during 1520-1600 were accompanied by food shortages, famines, flooding, peasant uprisings and religious wars" (Scott & Duncan, 2001, p. 291).

While drawing from primary sources about the frequency and intensity of demographic catastrophes, the presented here survey has been also assisted by some useful compilations (Austin Alchon, 2003; Kohn, 1995; Spignesi, 2002; White, 2011).

4. Examples of prominent demographic catastrophes

One of the earliest recorded devastating plagues was the Asiatic disease identified now as *tularaemia*, a bacterial disease caused by *Francisella tularensis*, first recorded around the early 1700s BC. It spread over a large area between Cyprus and Iraq and between Palestine and Syria. This disease appears to be also the first recorded example of the use of biological weapon when it was introduced deliberately to Anatolia (Trevisanato, 2004; 2007). The same disease has been also probably recorded in the Bible as causing a great number of deaths among Philistines in the city of Ashdod, the event dated either to around 1000 BC (Khan, 2004) or to 1320 BC (Cunha & Cunha, 2006).

Early recorded plagues include also a viral haemorrhagic fever in Egypt between 1500-1350 BC (Duncan & Scott, 2005) but it might have been the same disease as recorded earlier in Egypt and the same plague that decimated Philistines. Incidentally, Duncan & Scott (2005) claim that Black Death was not a bubonic plague caused by bacterium *Yersinia pestis*, as traditionally claimed, but rather that is was a viral haemorrhagic fever, which according to them includes also the plagues of Mesopotamia (700-350 BC), the Plague of Athens (430-427 BC), the Plague of Justinian (AD 541-542), Plagues of Islam (AD 627-744), plagues in Asia minor (1345-1348), and the plague of Denmark and Sweden (1710-1711).

The epidemic of Athens (460-399 BC) is claimed to have killed 25% of Athenian army and a great number of civilians (Austin Alchon, 2003). It created a turning point in the history of Greece (Ross, 2008). It is also claimed that this plague killed 50% of the army of Pericles and 50% of the navy coming to the rescue from Piraeus (Beran, 2008). The plague was triggered by the overcrowding of Athens when Spartan's attacks prompted rural population to seek shelter in that city, which was already housing a relatively large number of people, an estimated 300,000 citizens and around 3 million slaves.

The earliest large demographic catastrophe in the AD era appears to have been associated with the Red Eyebrows Revolt, which commenced around AD 2. The estimated size of Chinese population at that time is claimed to have been 59.6 million but it might have been reduced to 21 million in AD 57 (Durand, 1960). However, Durand also discusses possible inaccuracies in these estimates and presents corrected numbers of 74 million in AD 2 and 45 million in AD 88, for the entire Chinese Empire. He also estimates 71 million and 43 million, respectively, for the China proper (Durand, 1960, p. 221). By China proper he means the current 18 provinces. He uses this estimate in his graph (Durand, 1960, p. 247). In both cases, the relative death toll is approximately 39% of the original population in China but only a maximum of 12% of the global population, too weak to produce any noticeable impact.

The Red Eyebrows Revolt and the associated dramatic decrease in the size of population in China was in the middle of a massive demographic transition, one and only major demographic transition in the past 12,000, a transition from a fast to a slow hyperbolic trajectory, the transition which lasted for approximately 1000 years. This transition is shown in Figure 2. The dramatic event in China had no impact on the growth trajectory of the world population.

Durand points out also that estimates of the size of the population at the time of demographic catastrophes might be inaccurate. "Even if such huge loss were conceivable, it would be naïve to suppose that accurate count of the survivors could have been carried out in the midst of the ensuing chaos" (Durand, 1960, p. 224). White (2011) attributes only 10 million of casualties to the Red Eyebrows Revolt. However, to estimate the impact of this demographic catastrophe we shall use the revised estimate of Durand (1960) representing the total death toll of 29 million over 87 years.

Similar uncertainty in the estimated death toll applies also to the An Lu-Shan Rebellion (AD 756-763). Acceptable records appear to show the death toll of 36 million but White (2011) attributes only 13 million.

> Between A.D. 705 and 755 to all appearances the census machinery functioned much more effectively; but after 755 it broke down again. The recorded number of persons dropped from nearly 53 millions in the year 755 to only 17 millions in 760. During this time, China was torn by revolts which were suppressed with bloody force, including the notorious rebellion of An Lu-Shan. Many historians have affirmed that 36 million lives were lost as a result of these violent events, but Fitzgerald and others have shown that this is incredible (Durand, 1960, p. 223; Fitzgerald, 1936, 1947).

In order to maximise the possible impact of this demographic crisis, we shall assume that the death toll was 36 million.

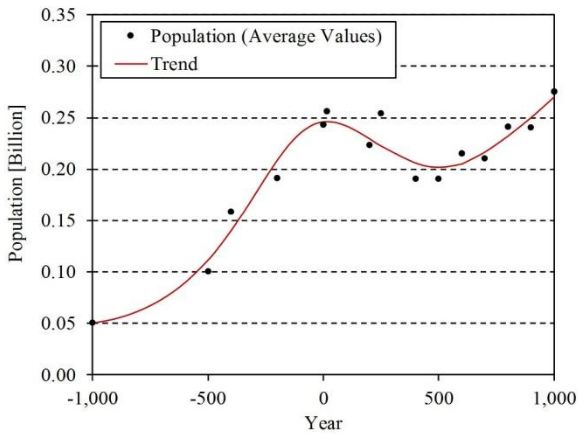

Figure 2. *Demographic transition in the growth of global population around AD 1. The transition can be described by the monotonically changing distribution (Nielsen, 2016j; 2017). Rebellion of An Lu-Shan, which caused a massive reduction in the size of population in China, had no impact on the growth of global population. For the reference to the sources of data and for the description of their analysis see Nielsen (2016j; 2017).*

The impact of the Plague of Justinian is hard to estimate because of the incomplete information combined with conflicting claims. The plague is claimed to have reduced the population of Constantinople by 40% between AD 541 and 542 (Austin Alchon, 2003). Cunha and Cunha (2006) estimated a 30% reduction of the population of the Roman Empire between AD 542 and 590, or a maximum of about 14 million out of the total of 48 million (Maddison, 2006; Seeck, 1921). "The plague so weakened the Roman Empire that not long after the plague had passed, Roman borders were overrun by Huns, Goths, Moors, and other 'barbarians'" (Cunha & Cunha, 2006). Rosen (2007) estimates that this plague killed 25 million people in a short time of only between AD 541 and 542. In around AD 549 the same plague emerged also in Britain (Carmichael, 2009). It is also claimed that "The Plague of Justinian recurred in discernible cycles of about nine to twelve years" (Dols, 1974, p. 373).

There is also one claim, which is distinctly different than all other estimates. Assisted by the Eurasian Silk Road, this plague was supposed to have spread to China in around AD 610, (Ross, 2008) continuing its devastation until around AD 700 (Duncan & Scott, 2005) and killing probably a maximum of about 100 million people (Ross, 2008), which would represent a 50% reduction in the *world* population. Even if we consider the regenerating effects of Malthusian positive checks (Malthus, 1798; Nielsen, 2016i), such a huge reduction should be reflected in the growth trajectory but it is not. By AD 500, the growth of the world population was at the end of its transition (see Figure 2) and commenced its new hyperbolic trend. In AD 500, the estimated size of the world population was only 190 million (Nielsen, 2016j and references therein). The claimed massive death toll of 100 million was supposed to have occurred between AD 610 and 700, i.e. when the growth of the world population settled already along a new hyperbolic trajectory, but we see no sign of such a disturbance. This claim of such a large death toll is almost certainly incorrect.

In our survey, in order to maximise the evidence *in favour* of the concept of Malthusian stagnation, we are considering the strongest impacts, which for the Plague of Justinian appears to be the death toll of 25 million in a very short time, between AD 541 and 542. We shall see later that, under this assumption, this plague had the strongest *overall* impact of all demographic catastrophes ever recorded, as manifested by *four out of five indicators*, and yet it caused no noticeable disturbance in the growth of the world population (see Figure 2).

Black Death (1343-1351) is another example of a massive demographic catastrophe and is claimed to have killed over 60% of the urban population in Asia, about 30% of the population of the Middle East and 30-60% of the population of Europe (Hawas, 2008). Beran (2008) claims that in many cities the death toll was over 90%, creating a severe hardship for the surviving population and adding to the total death toll caused also by the lack of food and lack of access to safe drinking water. The decaying corpses were also reducing the chance of survival. About 20% of the population of England died between AD 1348 and 1350 and a total of 50% by AD 1400 (Gilliam, 1961). Depending on the affected area, mortality rates varied between 25% and 70% (Cunha & Cunha, 2006). In terms of the total and relative death toll, Black Death was the greatest single demographic catastrophe ever recorded.

As mentioned earlier, plagues were also used as biological weapons by employing a gruesome practice of catapulting infected corpses at the walls of fortifications or hurling them over the walls by using trebuchets. This ghastly method was used by Greeks, Romans and other attackers between 300 BC and AD 1100, and by Tartars in AD 1346 against the residents of Genoa (Cunha & Cunha, 2006; Khan, 2004).

Other examples of large local casualties caused by demographic catastrophes include smallpox in Japan (AD 812-814), killing about half of the population of that country (Austin Alchon, 2003); the 1696 famine killing between 25% and 30% of the population of Finland (Jutikkala, 1955); the 1770 famine in Bengal, killing about 30% of the population (or a total of 10 million) and the 1376 famine in Italy, killing 60% of the population (Ghose 2002; Keys, *et al.,* 1950; Walford, 1878).

According to Mallory (1926), 18 provinces of China experienced 1015 draughts between AD 620 and 1619, or about one per year. However, they were unevenly distributed, illustrating that while the number of casualties and impacts of demographic catastrophes might be high in small and isolated regions, their effects could be much less severe when averaged over a larger number of population.

There was a total of 443 draughts in the Northern Division, 352 in the Central Division and 220 in the Southern Division. However, even within the same division, the number of draughts varied significantly between various districts. For instance, in the Northern Division, Honan District experienced a total of 112 draughts but Kansu Division only 4. In the Central Division, the largest number of draughts (113) was in the Chekiang District and the smallest (28) in the Anhwei District. In the Southern Division, the number of draughts varied between 4 and 59 per district.

The list of significant lethal events in China includes: 60-70% of troops killed during a single military engagement in AD 16; 70% of Mongolians killed by hunger in AD 46; 30-40% of troops killed in AD 162; about 70% of troops killed in a single military engagement and by famine and epidemic; close to 100% killed by locusts and famine in AD 312 in the northern and central China; over 30% killed in Shantung in AD 762; over 50% in Chekiang in AD 806; 30-40% in Hupeh, Kinagsu and Anhui in AD 891; 90% in Hopei in 1331; 50% of troops between 1351-1352; over 70% in Shansi in AD 135; 60-70% in Hupeh in 1354, and 100% in various towns and villages in Hunan in 1484 (Austin Alchon, 2003; McNeill, 1976)

It is claimed that in Mexico, 25-50% of the population died of smallpox (1520-1521), 60-90% probably of typhus (1531-1532), and over 50% of either the bubonic plague or typhus between 1576 and 1581 (Austin Alchon, 2003; Motolinía aka Fray Toribio de Benavente o Motolinía, 1971; del Paso y Troncoso, 1940; Prem, 1992).

The estimated death toll in the Andes between 1524 and 1591 includes 30-50% by smallpox (1524-1527), 25-30% by measles or bubonic plague (1531-1533), 15-20% by influenza, measles and smallpox (1558-1559), and about 50% by influenza, measles, smallpox and typhus between 1585 and 1591 (Cook, 1981; Dobyns, 1963). Dobyns (1993) gives also many examples of large death tolls, sometimes as high as 98% but most often close to 80-90%, caused by diseases among Native American population.

So, it appears that humans always lived with the threats and with deadly effects of demographic catastrophes strong enough to reduce often substantially the size of local populations. We shall now investigate their potential impact on the growth of the world population.

5. Indicators of impact

In order to study the potential impacts of demographic catastrophes we have to introduce a few useful gauge indicators. Their definition is assisted by the diagram presented in Figure 3.

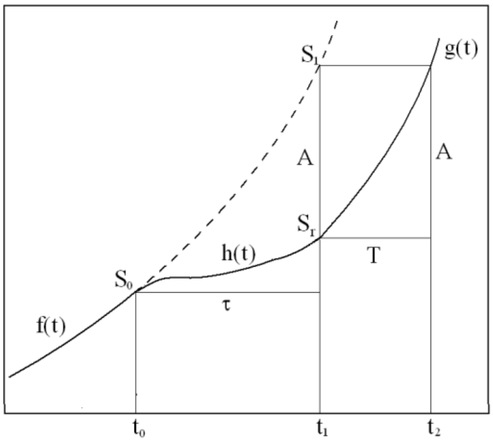

Figure 3. *Schematic diagram describing the composition of a demographic catastrophe. The leading parameters are: τ – the duration of demographic catastrophe; T – the recovery time; A – the death toll.*

Before the onset of a demographic catastrophe, the population increases along the trajectory $f(t)$. It reaches the size S_0 at the time t_0, which marks the beginning of the demographic catastrophe. The demographic crisis lasts for τ number of years, between the time t_0 and t_1. Depending on the intensity of the demographic catastrophe and on the efficiency of the process of regeneration (Malthus, 1798; Nielsen, 2016i), the growth of the population during the demographic crisis may be diverted to a new trajectory $h(t)$, which might be still increasing, remain constant or decreasing. At the end of crisis, the size of the population is S_r, which might be larger than, equal to, or smaller than the original size S_0. S_1, is the size of the population, which would have been reached if the crisis did not occur

When the crisis is over, the growth of population continues along a new trajectory $g(t)$ The quantity A is the death toll and T is the recovery time, i.e. the time required for the population to reach the size S_1.

Recovery time depends on the growth rate, *R*, during the time of crisis. Over a relatively small span of time associated with demographic catastrophes we can use linear approximations of the relevant trajectories.

$$R \equiv \frac{1}{S_r}\frac{dg(t)}{dt} \approx \frac{1}{S_r}\frac{A}{T} , \tag{3}$$

which gives

$$T = \frac{a}{R}, \tag{4}$$

where

$$a \equiv \frac{A}{S_r} \approx \frac{A}{S_0} \tag{5}$$

is *the relative impact*, i.e. the number of people killed by the demographic catastrophe as compared with the size of the population at the onset of crisis.

The growth rate R can be estimated by examining the population data around the time of crisis while the quantity a can be easily calculated using the reported number of people A killed by the crisis and the estimated size of the population at the beginning of crisis. Using these readily accessible quantities we can then calculate the recovery time T, which together with a (the relative number of people killed during demographic crisis) will help to gauge the intensity of the demographic catastrophe.

Another way of calculating the recovery time T is to use the exponential rather than linear approximation for the function $g(t)$. Under this assumption and using the well-known expression for the exponential function [eqn (2)] we can easily show that

$$T = \frac{1}{R}\ln\left(\frac{S_1}{S_r}\right) = \frac{1}{R}\ln(1 + a) \tag{6}$$

This is a general formula that does not have to be related to a demographic crisis. It is simply a formula for calculating the time needed for the exponential growth to increase from S_r to S_1, which happens to be precisely what we want to use to calculate the recovery time. For small a, the recovery time calculated using eqn (6) is virtually the same as by using the eqn (4). Thus, for instance, for $a = 20\%$, the recovery time calculated using eqn (6) is only 10% smaller than using eqn (4). For lower values of a, the discrepancy is even smaller. It increases to 23% for $a = 50\%$. As we shall soon see, in our survey of demographic catastrophes we shall be dealing with a values of up to only 20%.

If we use the hyperbolic approximation, then referring to the eqn (1), the recovery time is given by

$$T = \frac{A}{(S_r + A)kS_r}\,. \tag{7}$$

If we want to use an approximate expression incorporating the relative impact a, then using the eqn (1) and (5) we get

$$T = \frac{a^2}{A(1+a)k}\,. \tag{8}$$

So now rather than using just the parameter A (the total death toll) we have two additional gauge indicators, a and T, the parameters that give us additional information about the intensity of crisis.

However, we can also introduce yet another useful gauge indicator, which compares the recovery time with the duration of the demographic catastrophe. We shall call it the *intensity indicator (I)* and we shall define it simply as

$$I \equiv \frac{T}{\tau}. \tag{9}$$

If the recovery time T is large when compared with the duration of crisis, then we are dealing with a potentially strong demographic catastrophe. The larger was the recovery time compared with the duration of crisis the stronger was the devastating impact of crisis.

However, there is also another hidden information in this indicator. Using the diagram presented in Figure 3 and assuming that gradients of functions $f(t)$ and $g(t)$ are approximately the same, we can see that

$$I \approx \frac{A}{S_1 - S_0}. \tag{10}$$

If $A < S_1 - S_0$, then $I < 1$, which then indicates that population size continued to increase during crisis. If $A \approx S_1 - S_0$, then $I \approx 1$, which then indicates that the size of population remained approximately constant during crisis. If $A > S_1 - S_0$, then $I > 1$, which indicates that the size of population was decreasing during crisis.

Thus, by looking at the I indicator we can tell not only whether the crisis was weak or strong but also whether the population was still increasing, remained constant or decreasing during the crisis. However, even if $I > 1$ it does not mean that we a dealing with a potentially strong crisis, because depending on the duration of crisis the size of the population could still remain approximately constant. A potentially strong demographic crisis will be characterized by *I>>1*. A guide to the intensity indicator is presented in Table 1.

Finally, we can also introduce two other indicators: *the per annum relative impact* (α) and *the per annum intensity indicator* (β).

$$\alpha \equiv \frac{a}{\tau}, \tag{11}$$

$$\beta \equiv \frac{I}{\tau}. \tag{12}$$

The complete list of indicators used to evaluate the effects of demographic catastrophes is presented in Table 2.

Table 1. *A guide to the interpretation of the intensity indicator (I)*

$I < 1$	Weak crisis. Population continues to increase during crisis.
$I \approx 1$	Moderate crisis. Population size remains approximately constant during crisis.
$I > 1$	Moderate or potentially strong crisis depending on the value of *I*. Population size decreases during crisis.
I>>1	Potentially strong crisis

Table 2. *Indicators used to process information about demographic catastrophes*

Symbol/Definition	Description	Unit
t_0	The onset of crisis	*year*
A	Death toll	10^6
τ	Duration of crisis	*year*
$a = A / S_0$	The fraction of the population killed by crisis	%
$\alpha = a / \tau$	Per annum fraction of population killed by crisis	%/*year*
T	Recovery time	*year*
t_2	The year of the full recovery	*year*
$I = T / \tau$	Intensity indicator	
$\beta = I / \tau$	The per annum intensity indicator	$year^{-1}$

Note: Demographic catastrophe may be considered potentially strong if indicators $a = A / S_0$, $\alpha = a / \tau$, $T, I = T / \tau$ and $\beta = I / \tau$ are large.

6. Evaluation of impacts of demographic catastrophes

The survey of demographic catastrophes and their impacts is presented in Table 3. The summary of all impacts is shown in Table 4. In order to maximise evidence in favour of the postulate of Malthusian stagnation we have considered only the most significant demographic catastrophes characterised by the death toll of $A \geq 1$ million. Had we included smaller demographic catastrophes, the fraction of potentially strong catastrophes, which could have had noticeable impact on the growth of the world population, would have been significantly reduced.

The remarkable feature of this survey is that, in general and as revealed by the values of the introduced gauge indicators, even large catastrophic events had much smaller impact on the growth of the world population than it might have been expected by looking just at the death toll or at their reported local impacts. Indeed, we only have a few events that might have had a tangible impact, and they are all clustered around the early years of the AD era when the estimates of the total number of casualties were probably grossly exaggerated (Durand, 1960; Fitzgerald, 1936; 1947; Gilliam, 1961; Littman & Littman, 1973; Russel, 1968; Twigg, 1984, Watkins & Menken, 1985).

Table 3. *Survey of major demographic catastrophes AD 1-1900. The most significant values of gauge indicators are indicated by bold characters and moderately significant by italics. (Symbols are explained in Table 2.)*

Event	t_0	t_2	A	τ	a	α	T	I	β
Red Eyebrows Revolt	2	245	29.0	87	*11.5*	0.13	**157.5**	*1.8*	0.02
Antonine Plague	166	214	5.0	15	2.2	0.15	*34.1*	*2.3*	0.15
Plague of Justinian	541	756	25.0	2	*12.5*	**6.23**	**214.2**	**107.1**	**53.54**
An Lu-Shan Rebellion	756	845	36.0	8	**15.4**	*1.93*	**227.7**	*28.5*	*3.56*
N. Egypt Earthquake	1201	1206	1.5	1	0.5	0.46	4.8	*4.8*	*4.80*
Mongolian Conquest	1260	1405	40.0	35	*11.3*	0.32	**110.6**	*3.2*	0.09
Great European Famine	1315	1336	7.5	3	2.0	0.68	*19.1*	*6.4*	*2.13*
Famine in China	1333	1369	9.0	15	2.4	0.16	*21.8*	*1.5*	0.10
Black Death	1343	1530	75.0	9	19.7	*2.19*	**178.7**	*19.9*	*2.21*
Fall of the Yuan Dynasty	1351	1385	7.5	18	1.9	0.11	*17.4*	1.0	0.05
Sweating Sickness	1485	1556	3.0	67	0.6	0.01	4.6	0.1	0.00
Mexico Smallpox Epidemic	1520	1527	4.0	2	0.8	0.42	6.0	*3.0*	*1.50*
French Wars of Religion	1562	1602	3.0	37	0.6	0.02	3.7	0.1	0.00
Russia’s Time of Trouble	1598	1619	5.0	16	0.9	0.06	5.6	0.3	0.02
Fall of the Ming Dynasty	1618	1669	25.0	27	4.3	0.16	*25.2*	0.9	0.03
Thirty Years War	1618	1655	7.0	31	1.2	0.04	7.0	0.2	0.01
Deccan Famine in India	1630	1633	2.0	2	0.3	0.17	2.0	1.0	0.50
Famine in France	1693	1696	2.0	2	0.3	0.15	1.5	0.8	0.38
Bengal Famine	1769	1778	10.0	5	1.2	0.23	4.7	0.9	0.19
Napoleonic Wars	1803	1816	4.0	13	0.4	0.03	1.4	0.1	0.01
Famines in China	1810	1819	22.5	2	2.3	1.13	7.9	*3.9*	*1.96*
Great Irish Famine	1845	1850	1.0	6	0.1	0.01	0.2	0.0	0.01
Famine in China	1846	1849	11.3	1	1.0	0.96	2.8	*2.8*	*2.83*
Taiping Rebellion	1850	1868	20.0	15	1.6	0.11	4.5	0.3	0.02
Famine in India	1866	1866	1.0	1	0.1	0.08	0.2	0.2	0.20
Famine in Rajputana	1869	1869	1.5	1	0.1	0.11	0.3	0.3	0.29
Famine in Persia	1870	1871	2.0	2	0.1	0.07	0.4	0.2	0.10
Famine in N. China	1876	1880	13.0	3	0.9	0.31	2.3	0.8	0.25
British India Famine	1876	1903	17.0	25	1.1	0.05	2.6	0.1	0.00
Yellow River Flood	1887	1887	2.0	1	0.1	0.13	0.3	0.3	0.31
Famine in India	1896	1902	8.3	6	0.5	0.08	1.1	0.2	0.03

Table 4. *Summary of impacts of demographic catastrophes.*

Indicator	Impact	Number of Events	Fraction of Total [%]	Insignificant [%]
Relative impact (a)	Strong	2	6	
	Moderate	3	10	
	Negligible	26	84	94
Per annum relative impact (α)	Strong	1	3	
	Moderate	2	6	
	Negligible	28	91	97
Recovery time (T)	Strong	5	16	
	Moderate	5	16	
	Negligible	21	68	84
Intensity indicator (I)	Strong	1	3	
	Moderate	11	35	
	Negligible	19	62	97
Per annum intensity indicator (β)	Strong	1	3	
	Moderate	7	23	
	Negligible	23	74	97
The average of all five	Strong	2.0	6.5	
	Moderate	5.6	18.1	
	Negligible	23.4	75.4	93.5

Note: The attribute described as *strong* should be interpreted as *potentially strong* or *the strongest* of all impacts. This attribute does not identify impacts, which had a strong impact on the growth of population but only impacts, which were potentially strong enough to have a noticeable impact.

The leading indicator is the relative impact a because it gives the direct information about how the growth trajectory might have been affected by a given individual demographic catastrophe. Events for which a is less than or equal to around 10% can be ignored, because such displacements would be hardly noticeable on the trajectories describing the growth of population. The corresponding demographic catastrophes could be described as negligible. Even events with a up to around 20% could be expected to have only relatively small effect. However, in this survey we have two events (An Lu-Shan Rebellion and Black Death), with the relative impact of 15.4% and 19.7%, which we shall describe as having a potentially strong impact. They account for only 6% of all impacts. Thus 94% of all large demographic catastrophes, i.e. catastrophes with $A \geq 1$ million, were individually too weak to have a significant impact on the growth of the world population.

We should remember, however, that we are ignoring the spontaneous process of regeneration (Malthus, 1798; Nielsen, 2016i). By describing a crisis as strong we are only distinguishing it from other catastrophes. A strong crisis is only relatively strong or potentially strong. It is a crisis, which could have been reflected in the growth of population but considering the ever-present mechanism of regeneration its impact is likely to be significantly reduced.

If we consider the per annum impact measured by the indicator α, we can see that there was possibly only one event (Plague of Justinian) that might have had a relatively strong impact on the growth of the population and two (An Lu-Shan Rebellion and Black Death) that might have had a marginal impact. Thus, when measured by this indicator, 97% of all large demographic catastrophes had insignificant effect on the growth of the world population.

The recovery time (T) shows five significant events (Red Eyebrow Revolt, Plague of Justinian, An Lu-Shan Rebellion, Mongolian Conquest and Black Death). For all of them, the estimated recovery time was between around 100 and 200 years. They represent 16% of all demographic catastrophes, the largest fraction in this survey. However, even for this indicator, the fraction of negligible events is high, 84%. The majority of all large critical events could have potentially inflicted only negligible impact on the growth of population.

The intensity indicator (I) suggests only one prominent event (Plague of Justinian) and possibly 11 moderately strong events. This indicator, therefore, shows that 97% of all large demographic catastrophes could have had, at best, only small impact on the growth of the world population. For the per annum intensity indicator (β), the fraction of insignificant impacts is the same, 97%.

If we consider the average values of all five indicators we can see that only 6.5% of all demographic catastrophes with the death toll larger or equal to 1 million might have had a tangible impact on the growth of the world population. The remaining 93.5% were too weak to have any significant impact. It is, therefore, clear that demographic catastrophes were too weak to shape the trajectory of growth of the world population, particularly if we consider that demographic catastrophes trigger also a strong process of regeneration (Malthus, 1798; Nielsen, 2016i).

The generally large percentage of insignificant impacts is an overwhelming evidence contradicting the concept of Malthusian stagnation but confirming conclusions based on the analysis of distributions describing the growth of population and the economic growth (Nielsen, 2016a; 2016d; 2016j), the analysis showing the absence of convincing evidence of frequent impacts of demographic catastrophes.

It is also useful to notice certain correlations between gauge indicators because such correlations could give a closer insight into the process of demographic catastrophes. They can reveal what was happening during a given crisis. Thus, for instance, the intensity indicator *(I)* for the Mongolian Conquest shows that population was decreasing during this crisis but the per annum intensity indicator shows that the population was approximately constant. The intensity indicator was also not excessively large. The size of the population was decreasing but slowly. However, the recovery time was exceptionally high. We can explain it by noticing that the duration of the crisis was long.

Our survey shows also a unique convergence of *five* demographic catastrophes. They were: the Mongolian Conquest (1260-1295) with the total estimated death toll of 40 million; Great European Famine (1315-1318), 7.5 million; the 15-year Famine in China (1333-1348), 9 million; Black Death (1343-1352), 75 million; and the Fall of Yuan Dynasty (1351-1369), 7.5 million. Their combined maximum death toll was 139 million. The estimated size of the world population in AD 1250 was around 380 million. The combined maximum relative impact of this five catastrophes was, therefore, around 37%. Such a strong impact should be reflected in the growth of the world population and indeed it was but not as strongly as we could have expected (Nielsen, 2016j). It caused only a minor disturbance. During this crisis, the population was decreasing but very slowly to reach 360 million at the termination of these five catastrophes, illustrating the efficient process of regeneration even during this combined crisis. This crisis was followed by a faster growth and the lost time was soon recovered, the faster growth illustrating again the efficient process of spontaneous regeneration (Malthus, 1798; Nielsen, 2016i).

Before the crisis, the growth of population was following hyperbolic trajectory characterised by $k = 3.448 \times 10^{-3}$. If continued undisturbed, it would have reached the size $S_1 = 470$ million in around AD 1400. However, the actual size, S_r, at that time was 360 million. If the growth of population after the crisis continued along the same hyperbolic trajectory as before the crisis, then the recovery time, calculated using the eqn (7), would have been 224 years. However, after the crisis, the growth of population was following a faster trajectory, characterised by $k = 4.478 \times 10^{-3}$. So, if we use the eqn (7) again we can calculate that the corresponding recovery time for this faster trajectory was 173 years. The actual recovery time, as recorded by data, was around 165 years, which is in good agreement with the calculated value. The process of regenerations decreased the recovery time by 50-60 years.

7. Summary and conclusions

The study presented here adds to the explanation why demographic catastrophes did not shape the growth of population and the associated economic growth.

The currently accepted interpretation of the historical growth of population is succinctly summarised in the following statement: "Throughout human history, epidemics, wars and famines have shaped the growth path of population" (Lagerlöf, 2003a, p. 435). If such is the case we should have no problem with showing many examples of this mechanism but we cannot find them. We can analyse data going as far back as 2,000,000 years ago and we can see that with the exception of just one *minor* disturbance around AD 1300 there is no evidence of such effects (Nielsen, 2016j; 2017). We also see no evidence in the distributions describing regional growth of population (Nielsen, 2016d).

This imagined, but never proven mechanism, was supposed to have been responsible for creating an endless epoch of Malthusian stagnation characterised by irregular and generally stagnant state of growth of population and of economic growth, but data are in clear contradiction of this doctrine (Nielsen, 2016a; 2016d; 2016j; 2017; von Foerster, Mora & Amiot, 1960). It is a doctrine, which is based on the incorrect interpretation of hyperbolic growth.

The growth of population and economic growth were hyperbolic. It is a *monotonically* increasing growth. It is slow over a long time and fast over a short time but there is no stagnation and no takeoff or explosion at any time. Stagnation and explosion are just illusions, which readily disappear when we use the method of reciprocal values (Nielsen, 2014) to analyse data. What we see as a stagnation is just a monotonically increasing growth and what we see as an explosion is just the natural continuation of hyperbolic growth.

We have demonstrated that with the exception of just one event in the past 12,000 years (Nielsen, 2016j), and indeed in the past 2,000,000 years (Nielsen, 2017), there is no evidence that demographic catastrophes were ever shaping the growth of the world population. This unique event occurred around AD 1300 and coincides with *five* strong demographic catastrophes: the Mongolian Conquest (1260-1295) with the total estimated death toll of 40 million; Great European Famine (1315-1318), 7.5 million; the 15-year Famine in China (1333-1348), 9 million; Black Death (1343-1352), 75 million; and the Fall of Yuan Dynasty (1351-1369), 7.5 million. The combined death toll caused by them is estimated at a maximum of 139 million. At the onset of this unique event the world population was only about 380 million, so the relative impact should have been strong. This combined crisis lasted for about 280 years but it caused only a minor disturbance in the growth of population. At the end of this crisis, the size of population was reduced to only 360 million. There is also no convincing evidence that demographic catastrophes were shaping the growth of regional populations (Nielsen, 2016d). Likewise, there is no convincing evidence that they had any tangible impact on the economic growth, global or regional (Nielsen, 2016a).

We have already explained why demographic catastrophes did not shape the growth of population. We have demonstrated (Nielsen, 2016i) that, as first observed by Malthus (1798), his so-called positive checks (demographic catastrophes and many forms of harsh living conditions) are responsible not only for increasing the death toll but also for triggering the process of regeneration, reflecting the well-known phenomenon observed commonly in nature. Thus, the destructive action of even strong demographic catastrophes is quickly compensated by this process, which is likely to produce even faster growth than before.

We can now understand why a combination of five strong demographic catastrophes were needed to cause only minor and relatively short-lasting disturbance in the growth of population around AD 1300. This was one and only example in the past 2,000,000 years (Nielsen, 2017) when we can see a correlation between the growth of population and demographic catastrophes. Now we have added to this explanation by showing that individually, demographic catastrophes were generally too weak to have a tangible impact on the growth of population. On rare occasions, when they were strong enough to cause some minor damage, their action was quickly counteracted by the spontaneous and efficient process of regeneration (Malthus, 1798; Nielsen, 2016i).

We have defined a series of gauge indicators allowing for a study of impacts of demographic catastrophes. We have also concentrated our attention on the strongest catastrophes, thus maximising the fraction of potentially destructive impacts. Even then, this fraction turned out to be small. On average, only 6.5% of all major demographic catastrophes could have had a certain impact but as demonstrated by the analysis of relevant data (Nielsen, 2016d; 2016j; 2017) they had no impact. They were only relatively strong but even if they were stronger, such isolated actions could have been hardly expected to cause lasting disturbances in the growth trajectory, particularly if we consider the apparently ever-present process of regeneration (Malthus, 1798; Nielsen, 2016i).

Any negative impact on the growth of population could be expected to be reflected also in the economic growth but the analysis of data shows that the economic growth remained also undisturbed (Nielsen, 2016a). The growth of population and economic growth were exceptionally stable and generally uninterrupted. Demographic catastrophes *did not* shape the economic growth or the growth of population.

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